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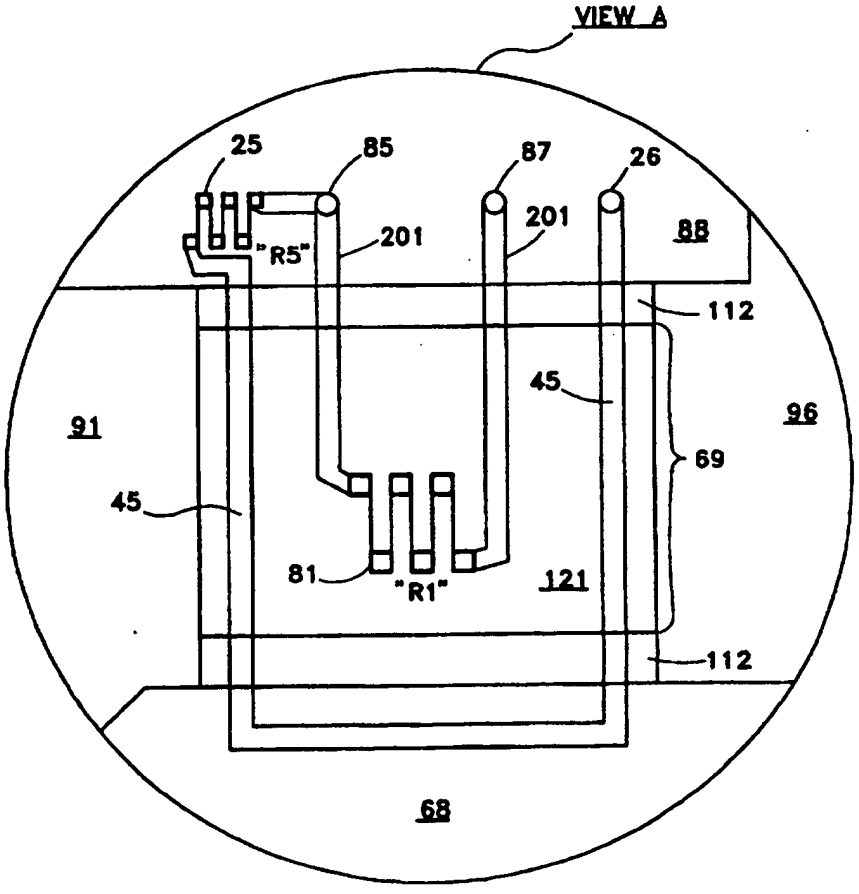
(54) Title: APPARATUS FOR DETECTION OF PROOF MASS RUPTURE IN AN ACCELEROMETER

(57) Abstract

A semiconductor sensor device measures a force being exerted thereon as a result of an acceleration of the semiconductor sensor device along a sensitive axis. The semiconductor sensor device comprises a flexure member having an outer plate (88) and an inner plate (68) separated from the outer plate by a groove (91) around the periphery of the inner plate, except by at least one hinge (69) for connecting the inner plate to the outer plate. The hinges are at predetermined locations around the periphery of the inner plate. Strain sensitive elements (81) are disposed on at least one of the hinges for providing an output signal deviation in accordance with the deviation of the inner plate as result of the force acting on the inner plate. A diagnostic conductor (45) is disposed on the semiconductor sensor device from a first predetermined point of the outer plate across the hinge to the inner plate and back across the hinge to a second predetermined point of the outer plate whereby the conductivity of the diagnostic conductor is measured between the first and second predetermined points of the outer plate to indicate a rupture of the hinge.



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APPARATUS FOR DETECTION OF PROOF MASS RUPTURE IN AN ACCELEROMETER

The present application is related to U.S. Patent application, Serial No. _____, entitled "Apparatus for Detection of a Diaphragm Rupture in a Pressure Sensor", by D. Wilda et al, filed on even date herewith, and assigned to Honeywell Inc., the assignee of the present application.

BACKGROUND OF THE INVENTION

The present invention relates to the field of instruments for measuring linear acceleration, and more particularly, to semiconductor accelerometers having a beam subject to stress as a result of the acceleration forces acting thereon and using piezoresistive elements for sensing changes in the stress. Silicon accelerometers of the forementioned type have a failure mode which is difficult to detect. During extreme loading of the proof mass (pendulum), the hinge (or beam) can rupture. This results in very low sensitivity of the remaining structure of the accelerometer and fails to give a positive indication of the failure, i.e., the rupture of the hinge.

Thus, there is a need to provide a more positive indication of the failure of the silicon accelerometer.

The present invention provides a positive indication of the failure and failure mode of the silicon accelerometer. A conductor is disposed across the hinge of the silicon chip (the potential rupture site), such that a circuit utilizing the conductor changes its operating characteristic dramatically in the case of a beam rupture thereby providing a positive indication of the failure mode, i.e., the rupture.

SUMMARY OF THE INVENTION

Therefore, there is provided by the present invention, an apparatus for detecting a rupture of a beam of a semiconductor accelerometer. A semiconductor sensor device measures a force along a sensitive axis, the force being exerted thereon as a result of an acceleration of the semiconductor sensor device along the sensitive axis. The semiconductor sensor device comprises a flexure member having an inner plate and an outer plate. The inner plate is separated from the outer plate by a groove around the periphery of the inner plate, except by at least one hinge for connecting the inner plate to the outer plate. The hinges are at predetermined locations around the periphery of the

inner plate. Further, the sensitive axis of the semiconductor sensor device is perpendicular to the inner plate. Stain sensitive elements are disposed on at least one of the hinges for providing an output signal deviation in accordance with the deviation of the inner plate as a result of the force acting on the inner plate along the sensitive axis. A diagnostic conductor is disposed on the semiconductor sensor device from a first predetermined point of the outer plate across the hinge to the inner plate and back across the hinge to a second predetermined point of the outer plate whereby the conductivity of the diagnostic conductor is measured between the first and second predetermined points of the outer plate to indicate a rupture of the hinge.

Accordingly, it is an object of the present invention to provide an apparatus for detecting a rupture of a beam of a semiconductor accelerometer.

These and other objects of the present invention will become more apparent when taken in conjunction with the following description and attached drawings, wherein like characters indicate like parts, and which drawings form a part of the present application.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a flexure member of a silicon accelerometer;

Figure 2 shows an isometric view of the flexure member of Figure 1;

Figure 3 shows a circuit diagram of micro circuitry disposed on the semiconductor material of the silicon accelerometer of the preferred embodiment of the present invention, including a strain bridge;

Figure 4 shows a cross-sectional view of the flexures (or hinges) of Figure 1;

Figure 5 shows an expanded top view of the flexures of the preferred embodiment of the present invention of the flexures of Figure 1; and

Figure 6 shows a configuration of an alternative embodiment for a diagnostic conductor.

DETAILED DESCRIPTION

Referring to Figure 1, there is shown a flexure member 63 of a semiconductor accelerometer (not shown). The flexure member 63 is a thin semiconductor material having an inner plate or pendulum 68 connected to an outer supporting or mounting plate 88 at flexures 69. (An isometric view of the flexure member 63 is shown in Figure 2.) In the preferred embodiment, the flexure member 63 is a sheet or substrate of single

crystal p-silicon of the desired diameter and is cut and polished to a desired thickness, for example 15 mils. From one face of this substrate is epitiaxially grown an etch-stop layer n-silicon about 1 mil in thickness. A circular groove 91 separates outer plate or ring 88 from inner plate or disk 68. Groove 91 is etched until the groove 91 becomes a slot passing entirely through the material thereby separating pendulum 68 from plate 88, the slot being enlarged at 96 to provide a passage way through member 63 for the positive and negative current leads 97 and 98, a ground lead 99, and an output conductor 100, all shown in Figure 3.

The broken line circle 101 about a center through which axis 22 passes in the assembled accelerometer of the preferred embodiment, shows an area of other elements (not shown) affixation to the disk, circle 102 shows the outer diameter of the other elements and circle 103 shows the inner diameter of damping rings (not shown). The surface of pendulum 68 readily outward from line 101 is available for applications of large scale integrated circuitry making up components 77-79, 89 and 90 of Figure 3 which will be described below. The pendulum 68 is supported by the outer ring 88 at flexures 69.

A portion of a strain bridge is applied to flexures 69 is shown greatly enlarged in Figure 4. Here, the heavily doped substrate is shown at 110, the epitaxially grown layer at 111 and the groove at 112. At each of the flexures 69 a first layer 120 and the second layer 121 of impurity boron are implanted to the opposite surfaces of the flexure 69 to form strain sensitive resistance elements.

Referring to Figure 3 there is shown a circuit diagram of the micro circuitry mentioned above, which includes a strain bridge 76, a preamplifier 77, a summing amplifier 78, a driving amplifier 79, and a readout resistor 80. Bridge 76 includes four strain sensitive resistors 81, 82, 83, and 84, connected in a bridge circuit and having input terminals 85 and 86, energized with direct current, and output terminals 87 and 88, giving a direct current bridge signal representative of the deviation of the pendulum at its flexures from its mechanical null. The bridge signal is amplified in preamplifier 77. The deviation of the pendulum measured at its flexures 69 is related to the forces acting on the pendulum 68 as a result of acceleration measured in the direction of the axis 22. A more detailed description of the accelerometer of the semiconductor accelerometer of the preferred embodiment can be had by reference to U.S. Patent No. 4,498,342,

entitled "Integrated Silicon Accelerometer with Stress-free Rebalancing", assigned to the assignee of the present application.

Referring to Figure 5, there is shown view A of Figure 1, which is an enlarged diagram of the flexure 69. The topside of the flexure 69 includes a piezo resistor R1 81. This resistor 81 is disposed on the surface 121 of the flexure 69 in a manner well know to those skilled in the art. The resistor 81 is connected to bonding pads 85, 87 via conductors 201. In a like fashion as discussed above, resistor 82 is disposed on the underside of flexure 69 on surface 120, and also in a like fashion resistors R3 and R4 83, 84 are disposed on the other flexure 69. In the preferred embodiment of the preferred invention, resistive element R5 25 is placed on the outer ring 88 to measure temperature of the substrate 63 thereby providing inputs to permit temperature compensation of the resistor elements R1-R4 81-84 with respect to temperature. Resistor R5 is one resistor out of four of an external Wheatstone bridge i.e., a Wheatstone bridge having the three other resistive elements external to the flexure element 63 and thus insensitive to the flexure temperature. Thus, by having a diagnostic conductor 45 of the resistor R5 cross the area susceptible to rupture, specifically the hinge or beam 69, the resultant signal of the external Wheatstone bridge will go to half of the supply voltage if the pendulum (or proof mass) is separated from the beam. This is easily detectable from the normal temperature signal which is typically in the millivolt range. This results in a positive indication that the pendulum 68 has ruptured (a rupture of the hinge resulting in a rupture of the diagnostic conductor 45) at the flexure area 69 and the accelerometer needs to be replaced or repaired. This positive indication is an effective diagnostic indication.

It will be recognized by those skilled in the art that detection of the rupture of the beam can be accomplished by an external half bridge circuit which can be achieved independent of (rather than) in conjunction with the temperature compensation as described above, or independent of any other measurement. The diagnostic conductor 45 associated with resistor R5 which crosses the beam can be utilized to connect that external element and the conductivity of the diagnostic conductor 45 measured in many ways well known to those skilled in the art. Further, it will be recognized that the semiconductor accelerometer can have various configurations including single or multiple (more than two) beams.

In an alternative embodiment, as shown in Figure 6, the diagnostic conductor 45 can be configured such that it crossed a first hinge 69 once from the outer plate 88 to the pendulum 68 and has a return path across a second hinge 69 to the outer plate. Bonding posts on the outer plate 88 can then be utilized to connect the diagnostic conductor 45 to a temperature compensation resistor 25, and can be connected to external circuitry (not shown) to measure the conductivity of the diagnostic conductor 45 for an indication of hinge rupture. It will be understood by those skilled in the art that the diagnostic conductor 45 can have many configurations depending on a number of factors, including the number of hinges,....

While there has been shown what is considered the preferred embodiment of the present invention, it will be manifest that any changes and modifications can be made therein without departing from the essential spirit and scope of the invention. It is intended, therefore, in the annexed claims to cover all such changes and modifications which fall within the true scope of the invention.

CLAIMS

Claim 1. A semiconductor sensor device for measuring a force along a sensitive axis of the semiconductor sensor device, the force being exerted thereon as a result of an acceleration of the semiconductor sensor device along the sensitive axis, the semiconductor sensor device comprising:

a) a flexure member having an inner plate and an outer plate, the inner plate being separated from the outer plate by a groove around the periphery of the inner plate, except by at least one hinge for connecting the inner plate to the outer plate, the hinges being at predetermined locations around the periphery of the inner plate, the sensitive axis of the semiconductor sensor device being perpendicular to the inner plate;

b) at least one strain sensitive element, disposed on at least one of the hinges, for providing an output signal deviation in accordance with the deviation of the inner plate as a result of the force acting on the inner plate along the sensitive axis; and

c) a diagnostic conductor disposed on the semiconductor sensor device from a first predetermined point of the outer plate across the hinge to the inner plate and back across the hinge to a second predetermined point of the outer plate whereby the conductivity of the diagnostic conductor is measured between the first and second predetermined points of the outer plate to indicate a rupture of the hinge.

Claim 2. A semiconductor sensor device for measuring a force along a sensitive axis of the semiconductor sensor device, the force being exerted thereon as a result of an acceleration of the semiconductor sensor device along the sensitive axis, the semiconductor sensor device comprising:

a) a flexure member having an inner plate and an outer plate, the inner plate being separated from the outer plate by a groove around the periphery of the inner plate, except by at least one first hinge and one second hinge for connecting the inner plate to the outer plate, the first and second hinges being at predetermined locations around the periphery

of the inner plate, the sensitive axis of the semiconductor sensor device being perpendicular to the inner plate;

b) at least one strain sensitive element, disposed on at least one of the first and second hinges, for providing an output signal deviation in accordance with the deviation of the inner plate as a result of the force acting on the inner plate along the sensitive axis; and

c) a diagnostic conductor disposed on the semiconductor sensor device from a first predetermined point of the outer plate across the first hinge to the inner plate, along the inner plate to the second hinge, and back across the second hinge to a second predetermined point of the outer plate whereby the conductivity of the diagnostic conductor is measured between the first and second predetermined points of the outer plate to indicate a rupture of the hinge.

Claim 3. A semiconductor device according to Claim 1, wherein said strain sensitive elements are piezoresistive elements.

Claim 4. A semiconductor device according to Claim 2, wherein said strain sensitive elements are piezoresistive elements.

Claim 5. A semiconductor device according to Claim 1, wherein the conductivity of said diagnostic conductor is measured external to said semiconductor device.

Claim 6. A semiconductor device according to Claim 2, wherein the conductivity of said diagnostic conductor is measured external to said semiconductor device.

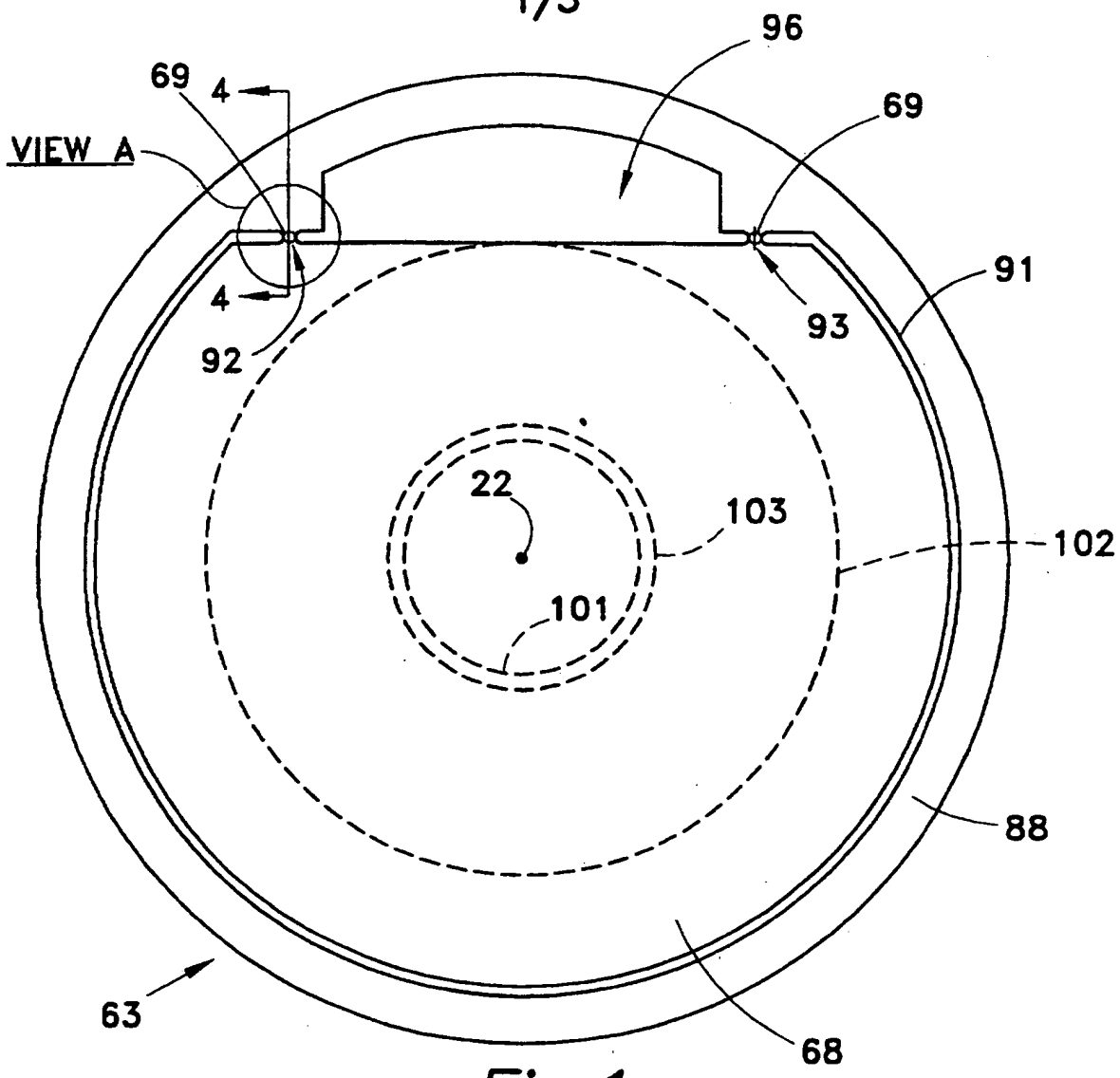
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Fig. 1

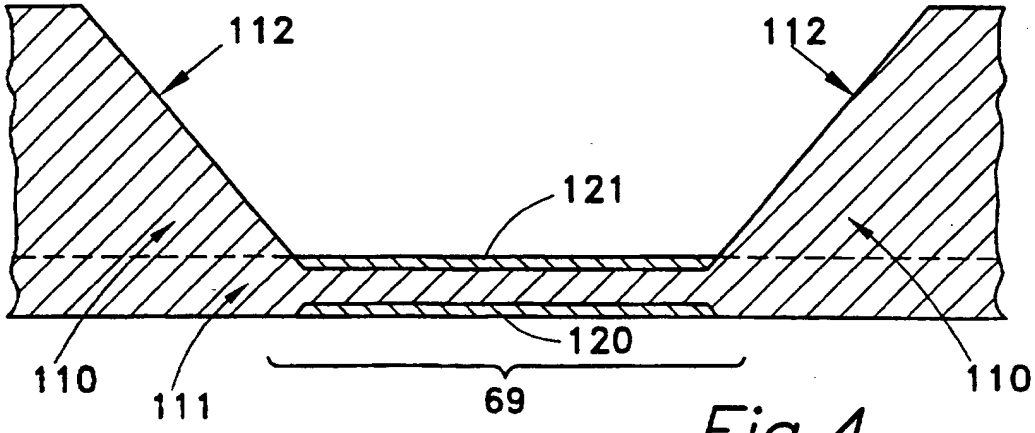
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Fig. 4

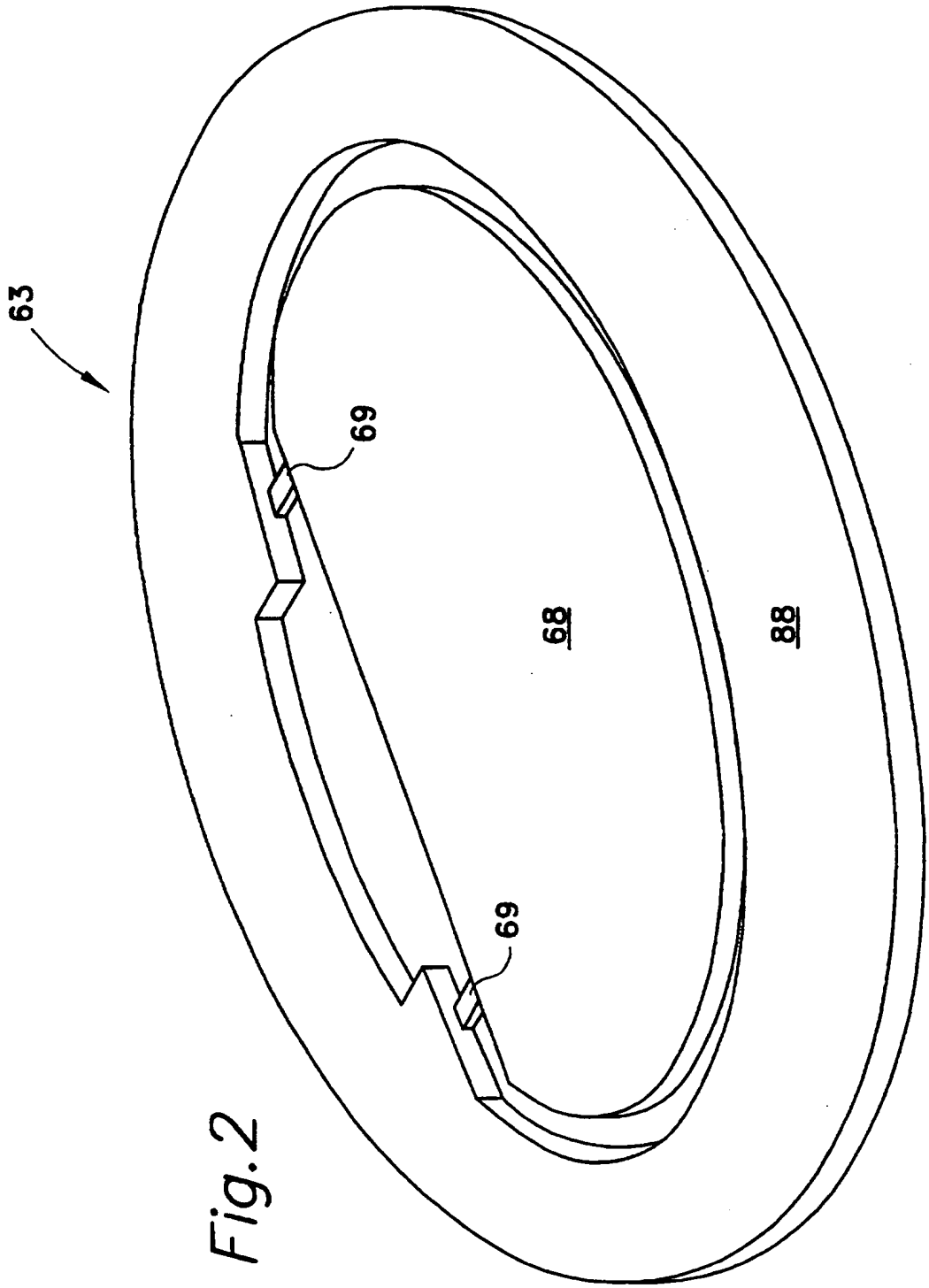

Fig.2

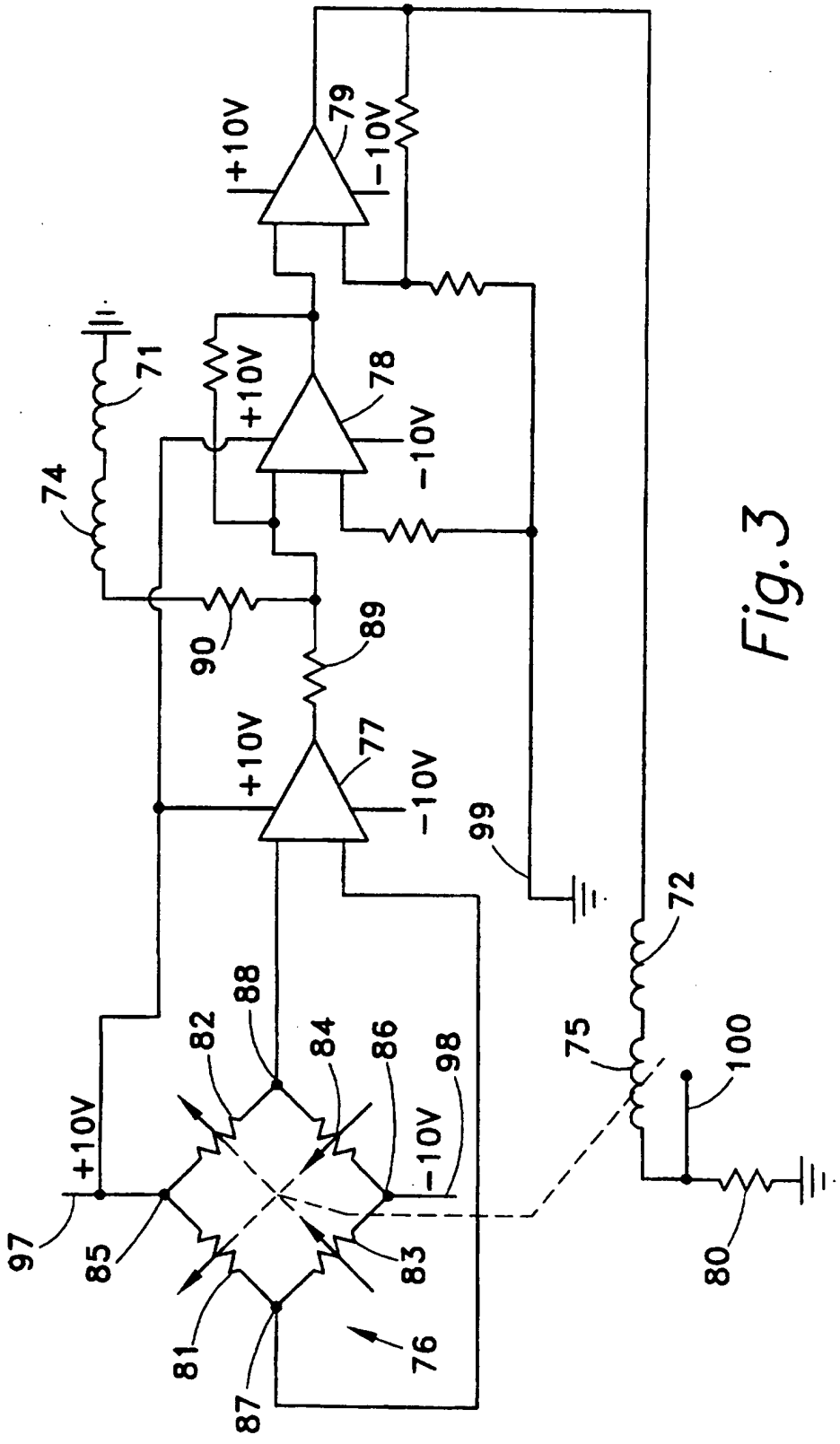
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Fig. 3

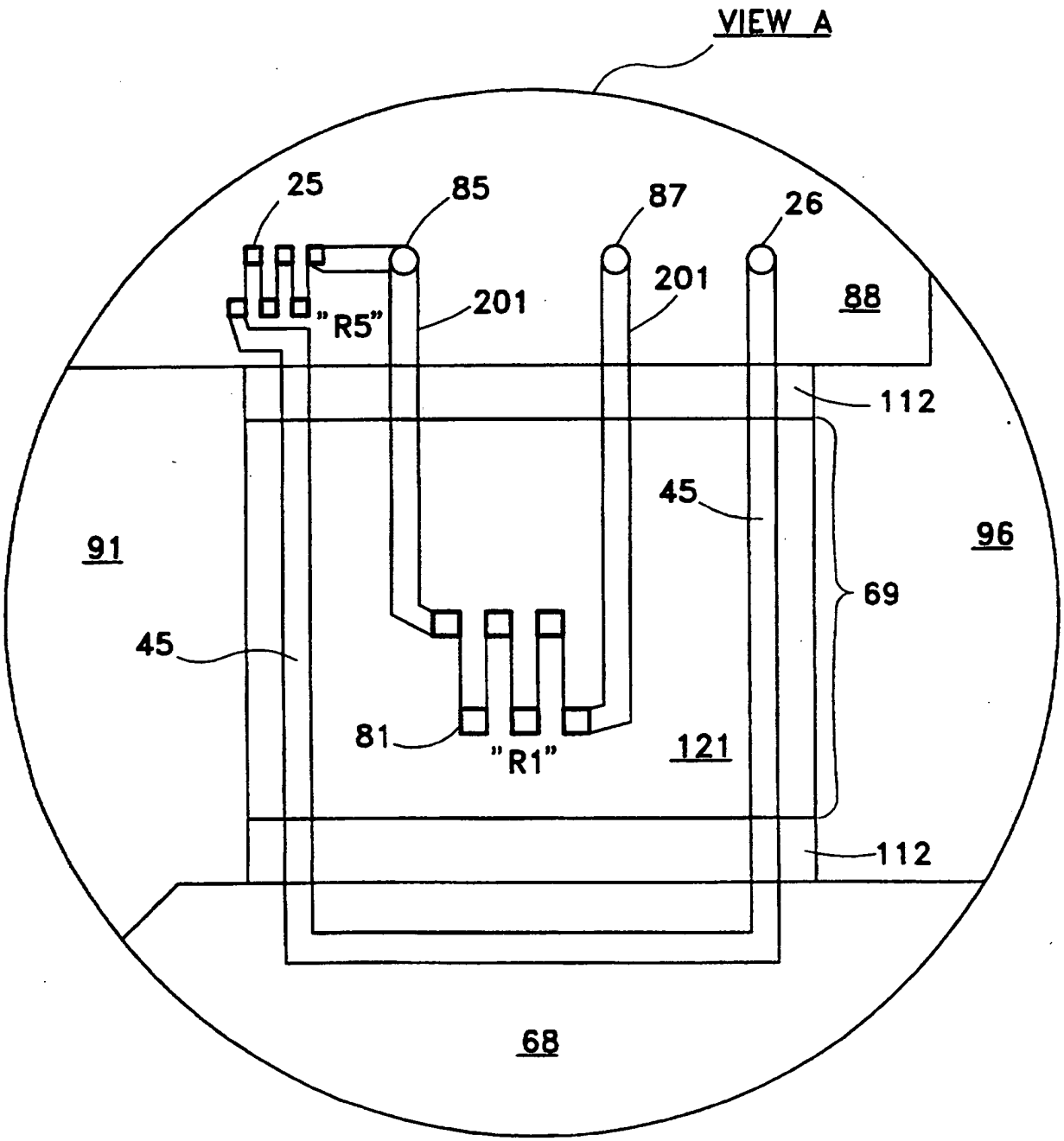

Fig. 5

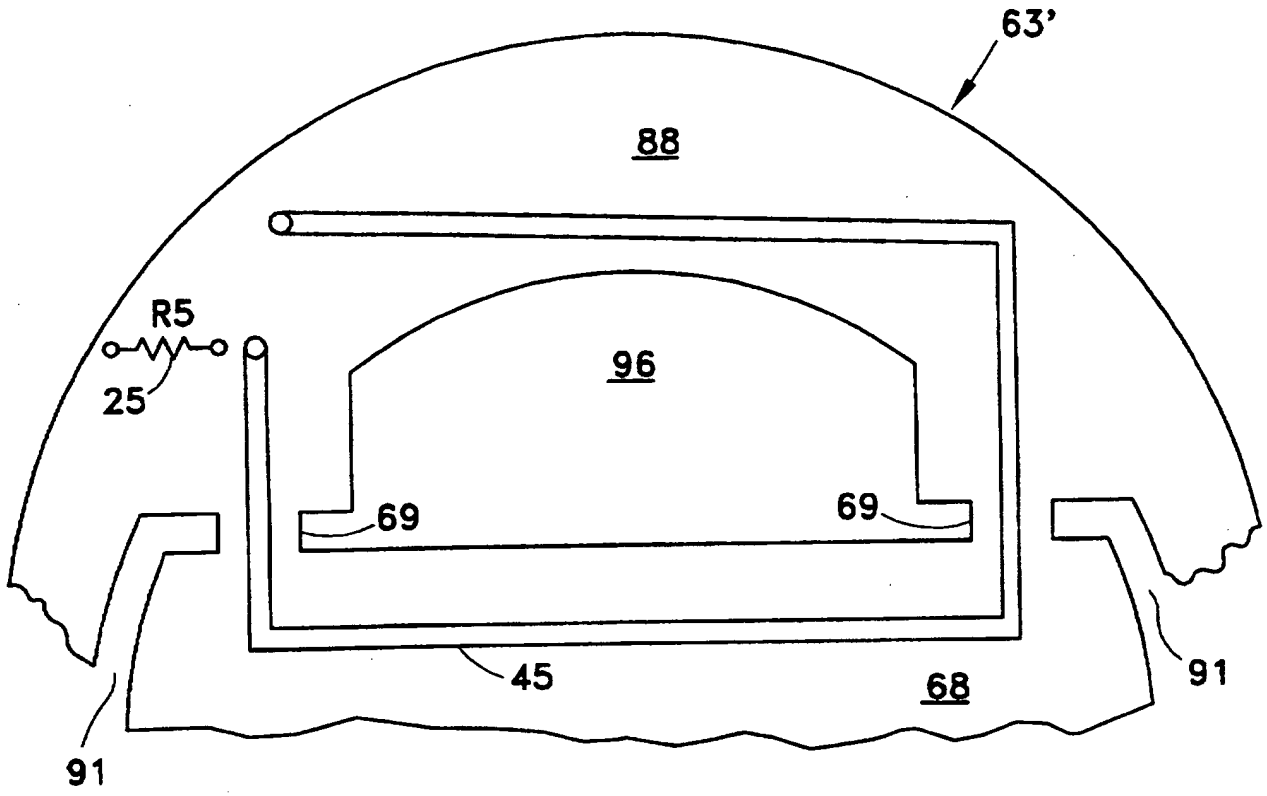

Fig. 6

INTERNATIONAL SEARCH REPORT

Int. ional Application No
PCT/US 96/01915

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01P21/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP,A,0 171 056 (TEXAS INSTRUMENTS DEUTSCHLAND) 12 February 1986 see page 5, line 4 - page 6, paragraph 1; figures	1-6
Y	US,A,4 498 342 (ASKE VERNON H) 12 February 1985 cited in the application see the whole document	1-4
Y	DE,A,43 44 284 (MITSUBISHI ELECTRIC CORP) 30 June 1994 see column 3, last paragraph - column 4, paragraph 1; figures 1-3	1-4
A	DE,C,38 14 949 (BOSCH) 3 August 1989 see column 2, line 65 - column 3, line 11; figures	1-6

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE,A,43 24 692 (BOSCH GMBH ROBERT) 26 January 1995 see column 3, paragraph 1; figures 1,2	1-6

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
EP-A-0171056	12-02-86	DE-C-	3429250	27-03-86
		US-A-	4641539	10-02-87
US-A-4498342	12-02-85	NONE		
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		EP-A-	0376995	11-07-90
		JP-T-	2504078	22-11-90
		US-A-	5107708	28-04-92
DE-A-4324692	26-01-95	JP-A-	7077466	20-03-95
		US-A-	5499541	19-03-96